FINAL REPORT

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The last phase of this contract involved the following four tasks.

Task 1. Modify the calibration routines to calibrate the Inertial Measurement Unit gyroscope drifts with fixed platform heading.

Task 2. Modify the calibration routines to calibrate the Inertial Measurement Unit accelerometers.

Task 3. Check overall software again for errors.

Task 4. Provide documentation on the above work describing changes to the present software, results of these changes and future operating procedures.

These tasks were funded in two stages, Tasks 1 and 4, and then Tasks 2 and 3.

These tasks involved designing, writing, debugging and checking in the laboratory of calibration software to improve the calibration of the inertial platform measuring unit gyroscopes and accelerometers.

The navigation program is implemented as a wander axis system where the heading axis is not torqued. This frees the system of azimuth torquer errors. Azimuth gyro drift must be measured and used to calculate platform heading. It also means that the platform alignment for navigational use is quicker because the cluster does not have to be physically rotated under torque drive to line it up to true north. True north is determined by calculations and used this way. In the original implementation of the software the gyroscopic biases were measured by recording the torquer pulses needed to keep the platform level during a leveled exercise at a fixed location. This enables the torques needed to keep the platform level as the earth rotates, to be measured and hence to derive a torque rate offset needed to overcome gyroscope drifts. By measuring each gyroscope in reversed positions average offsets for each of the two horizontal gyroscopes are determined.

This process takes several hours, during which a nontorqued azimuth axis allows direction of the gyroscope being calibrated to drift away from the axis of the earth. While mathematically this transformation should not cause any problems, in practice the integration of the discrete pulses which measure the level attitude, and the discrete nature of the torquing pulses may accumulate small errors. In addition, and more important, there are forces between the instrument and the case (mostly magnetic) which change as the heading of the platform changes relative to the case. This force cannot be properly removed from the free azimuth calculation as its exact nature is not known.

Task 1

This task was to provide the azimuth torque needed to keep the instrument cluster aligned so true north and the gyro axis remain fixed during the gyro bias measurement. Thus the effects of the case are not continually changing and the leveling loops are more stable. Appendix A describes this process in detail and provides the written documentation required under Task 4.

The gyrocompass software has been modified to compensate for small effects due to the position of the inertial instrument cluster relative to the external case. This software is used to align the platform to the vertical before navigation starts and is thus critical to the accuracy of the system. It also is used to derive the gyro biases, the slow drift of an undisturbed platform relative to the fixed stars. Inaccuracies here also affect the platform's performance. In the past it was noted that the platform showed less error when it was aligned at the same orientation as when the gyro biases were measured. When the platform is flown in an airplane the inertial instrument cluster will be at an unpredictable angle relative to the case when the system is powered up. In the previous software the platform was then aligned without concern for this angle. The new version rotates the platform to the same orientation every time.

Then as alignment proceeds, the platform is torqued about all three axes at a rate to compensate for the earth's rotation. Thus only drifts due to the gyro biases remain. The gyrocompass software measures these with a series of least square fits. Between fits the platform is adjusted so that it stays close to the original alignment. This keeps the platform level and prevents it from rotating so that the effects due to the case are effectively constant.

The navigation software is little changed. The platform is still not torqued about the vertical axis in navigation mode, but is allowed to drift in "wander azimuth" mode. The generation of the CRT display has been more evenly distributed through time. In the previous version of the program there were probably occasional time steps greater than the nominal 0.1 second. The program attempts to keep the <u>average</u> time step exactly at 0.1 second to the accuracy of the crystal clock. If a time interval is longer than 0.1 second by, say, a millisecond, a later time step is shortened by the same amount to compensate.

One change in the navigation program could affect its operation although this is not likely. The navigation software has been split off from the rest of the program and compiled separately. This was done because the program had grown to the point that the text editor was failing occasionally. The editor sometimes fails when editing a file between 64K and 128K bytes, the maximum. The surgery was done with some care, but only flight testing will assure that the two halves of the software communicate correctly. The only testing that has been possible so far are static drift runs.

The new gyro bias calibration software locks into the platform performance more quickly than the old. The previous version tended to do a slow damped oscillation before settling down to the bias values. This is especially true for the vertical axis. This should translate into better alignment before each flight. It is not possible to tell if the accelerometer scale factors will improve performance without doing actual flight tests. The tests so far have only been static drift runs. The scale factors do not affect drift runs unless they are grossly wrong. Drift runs show average velocity (i.e. errors) of about 1 knot over a 5 hour period. Again, it should be stressed that enough changes have been made from the earlier version of this software that it should be flight tested before it is used as a replacement for the old version.

Task 2

In this task the software for calibrating the horizontal accelerometers was designed, written, debugged and checked out in the laboratory. The offset and scale factor of the accelerometer drift slightly as they age and for the best performance they need to be periodically recalibrated. To accomplish this the platform cluster with the accelerometers must be placed on its side and then rotated by 90° steps. The case needs to be mounted rigidly at an angle tilted around the roll axis from the vertical, in excess of about 60°. It is likely that the case can be stood on one end if blocks are provided to keep the ball mount above the surface, provided the cooling air and the cables function and the case is kept rigid. However our laboratory fixture was used in this work where the platform is mounted in a proper fixture and rotated by 70° in roll and this, because of its rigidity is preferable. The "cage" operation rolls the gymbals until the z axis is normal to the bottom of the case. With the input pulses from the accelerometers and the torque pulses appropriately reassigned, the platform can be operated with the z axis horizontal and either the x axis or the y axis vertical.

The accelerometer pulses of the vertical accelerometer (now the x axis or the y axis) are then counted over a specified time of about 5 minutes. The exact arrival time of the last pulse is measured in this system so that the discreteness of the pulses counted does not limit the accuracy. This procedure is repeated at 90° intervals so the accelerometer pulse rate for $\pm$ 1 g is measured for both the x and the y accelerometers. Half of the sum of the + and - counts for each accelerometer gives the scale factor while half the difference provides the accelerometer bias. The z axis accelerometer is not calibrated in this procedure, but since the vertical axis must be used in an altitude loop a precise calibration is not necessary.

Task 3

Check overall software for errors. In the expensive testing and development no errors were discovered, so, unless flight tests reveal some problem it can be assumed the software is error-free.

Task 4

Provide documentation. The software has been delivered on the floppy disk medium used in this system together with documentation to use the software developed under Tasks 1 and 2. A copy of the operating instructions is attached as Appendix A.

APPENDIX A

Operating Procedures for Calibrating Inertial Platform Accelerometers

Introduction

The inertial navigation software has been upgraded to include the calibration of horizontal accelerometer scale factors as well as internal changes to the alignment/calibration portion of the navigation software. The operating instructions for the navigation program, J/GYRO, remain the same as before. The only changes that affect the user are the inclusion of more parameters in the file J/DATA. This is described below. There is a new program, J/AXCAL, which calibrates the horizontal axis accelerometers. This document gives operating procedures for J/AXCAL.

The Parameter File

The file J/DATA is associated with a particular inertial platform. It provides the navigation and axis calibration programs with data about the platform. Under the old program only the first 3 lines of this file were significant. Now a fourth and fifth line have been added for the accelerometer scale factors and zero offsets. Trial values for the scale factors may be obtained from the platform case. There should be a sticker labeled "Gyro Constants". The scale factor for axis 1 is labeled "x" and that for axis 2 is labeled "y". The scale factor for axis 3 should always be set to 1.0. The offsets should be set to zero initially. The following table details this.

Line	Columns	Item	Trial Value
4	1-10	axis 1 scale factor	from case
	11-20	axis 2 scale factor	from case
	21-30	1.0 (axis 3 scale factor)	1.0
5	1-10	axis 1 zero offset	0.0
	11-20	axis 2 zero offset	0.0
	21-30	0.0 (axis 3 zero offset)	0.0

After running J/AXCAL the trial values should be replaced with the computer calibrated values. The ED editor may be used to modify the file J/DATA. (This editor is very similar to the UNIX editors ed and ex.) Note: neither J/GYRO nor J/AXCAL will function without the data on lines 4 and 5.

Axis Calibration

The calibration of the horizontal accelerometers is accomplished by placing the platform on its side so that each horizontal axis can be set vertically. The earth's gravity provides a constant acceleration along the axis being tested. The platform is then slewed 90° to bring the next axis into a vertical position. Four measurements are needed: the two axes are oriented each upward and downward. The most important datum needed for this procedure is the local acceleration of gravity in ft/sec^2. This should be known to at least one part in 10^5. Accuracy greater than this is not useful since the calibration procedure is not repeatable to better than a few parts in 10^5.

During calibration mount the platform solidly on its side in an almost horizontal position. There should be a minimum of vibration and the case should not shift. (A concrete floored room in the lower stories of an office building would be ideal.) The platform should not be totally on its side (with the connectors uppermost, and rotated clockwise about the north direction); a tilt of 60° to 80° from its normal orientation is all that is needed.

In detail the procedure is as follows.

1. Assemble the platform hardware in its normal configuration except that the platform lies tipped on its side.

2. Bootstrap the computer.

   a. Turn on the computer and CRT.

   b. When "*" characters appear, type U and then I, but no return characters.

   c. Wait for the message to appear

      END SUBMIT LOGIN

      followed by a "-" prompt character.

3. Start the axis calibration program.

   a. Turn on the platform power.

   b. Type J/AXCAL. After a few moments a display with a flashing screen appears with a request to type in the date, time, and gravitational acceleration. The typed information will appear in the next to the bottom line of display.

   c. Type in the date. If the date were July 4, 1976, type:

      DATE 7 4 76 (return character at end of line)

   d. Type in the time. If the time were 9:37 type:

      TIME 9 37

   e. Type in the local acceleration due to gravity in ft/sec^2. If this were 32.1578, type:

      GRAV 32.1578

When the date, time, and gravity (in any order) have been received by the program, the screen will stop flashing and the calibration can proceed.

4. Let the hardware warm up. The display will announce a number of modes such as CAGING, FAST LEVEL, SLEW, and AXIS CALIBRATION. By the time the program has been in AXIS CALIBRATION mode for 15 minutes, the hardware has warmed up sufficiently to proceed.

5. Take the first measurement.

   a. Type RECAL to restart the accumulation of data.

   b. Wait 5 minutes for sufficient data to be taken.

   c. Type ADV to advance the platform through 90° for the next step. The program will enter SLEW mode taking about 10 minutes to rotate the next axis to vertical.

6,7,8. Each of the next steps is the same.

   a. When the display returns to AXIS CALIBRATION mode, wait 5 minutes for the orientation of the platform to stabilize.

   b. Type RECAL to start the collection of data.

   c. Wait 5 minutes for data to accumulate.

   d. Type ADV to advance to the next step.

9. The ADV command at the end of step 8 sends the platform back to the same orientation that existed in step 5 This is reflected by the displayed variable STAGE which cycles through 1,2,3,4 for each of the 4 possible orientations of the platform. The actual STAGE that occurs first will depend on how the platform was sitting inside its case when calibration started. The final result of the calibration is available when the ADV command is typed in step 8. The line labeled:

AXIS 1 CALIBRATED SCALE FACTOR

gives the scale factor and offset for axis 1 and the line labeled:

AXIS 2 CALIBRATED SCALE FACTOR

gives those for axis 2. Axis 3 is not calibrated. These numbers should be entered into the file J/DATA so that they can be used for the navigation program J/GYRO.